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Do Confounding or Selection Factors of Residential Wiring Codes and Magnetic Fields Distort Findings of Electromagnetic Fields Studies?

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In contrast with several previous studies, our recent large case-control study found little association between childhood acute lymphoblastic leukemia (ALL) and electric-power-line wire codes. Here we examine internal evidence from our study to assess the possibility that selection bias and/or confounding may have affected the findings. We compared the relation between childhood ALL and wire codes and direct measurements of magnetic fields in subjects who participated in all phases of the study with the relation in all subjects, including those who declined to allow access inside the home. We found that the odds ratio for ALL among those living in homes with very high current configurations increased by 23% when 107 "partial participants" were excluded. We found similar, but slightly smaller, increases in the odds ratios when we performed the same comparisons using direct measurements of magnetic

fields, excluding subjects who allowed only a measurement outside the front door. "Partial participants" tended to be characterized by lower socioeconomic status than subjects who participated fully, suggesting possible selection bias. We also examined the relation between a large number of potential confounding variables and both proxy and direct measurements of magnetic fields. Univariate adjustment for individual variables changed the odds ratio for ALL by less than 8%, while simultaneous adjustment for several factors reduced the estimate by a maximum of 15%. We conclude that while confounding alone is unlikely to be an important source of bias in our own and previous studies of magnetic fields, selection bias may be more of a concern, particularly in light of the generally low response rates among controls in case-control studies. (*Epidemiology* 2000;11:189-198)

Keywords: selection bias, confounding, magnetic fields, wire codes, childhood leukemia, case-control studies.

Every epidemiologic study is susceptible to bias due to confounding by uncontrolled risk factors and from factors relating to identification and participation of study subjects. The purpose of this paper is to examine carefully internal evidence from a large case-control study of magnetic field exposures and childhood leukemia¹ to assess the extent and direction of these biases and to evaluate whether similar biases may have affected the results of previous studies.

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The question of whether magnetic field exposures cause cancer has been controversial for 20 years, since Wertheimer reported an association between "wire coding," a proxy measure of magnetic field exposure, and deaths due to childhood cancer.² Similar results were found in subsequent studies,^{3,4} although many authors speculated that either uncontrolled confounding or selection factors may have accounted for the wire code association.⁵⁻⁷ In an earlier paper, we investigated the potential for selection bias by examining the distribution of wire codes among 119 potential controls who declined to participate in the study during random digit dialing.⁸ In this report, we take advantage of components of the study that allow us to address directly the question of selection bias. In particular, because data collection occurred in three separate phases, we are able to contrast our results using subjects who participated in all phases of the study ('complete' participants) to results obtained using both 'partial' and 'complete' participants. We also evaluate characteristics of partial participants to determine whether they differ systematically from complete participants.

Only limited data have been previously reported on the association of either wire codes or measured fields

and potential confounding variables,^{6,9,10} and none within a study of childhood leukemia. Here we examine systematically the extent that confounding bias actually affected our results by using extensive information collected during our study on potential confounding variables, including residential, geographic, sociodemographic, and behavioral characteristics of children and their parents. By evaluating the evidence on confounding and selection bias within our own study, we also hope to shed some light on the likelihood that these biases were present in previous electromagnetic fields (EMF) studies.

Methods

Our study methods⁸ and the relation between wire code levels and measured fields¹¹ are reported elsewhere. Below, the methods for the wire coding and MF measurement components of the study are briefly summarized.

WIRE CODING

Two technicians, blinded to case-control status, diagrammed power lines near each subject's residence according to the method developed by Wertheimer and Leeper,² which takes into account distance and configuration of power lines. A computer algorithm assigned a wire code level to each subject's residence using the Wertheimer-Leeper classification scheme: very low current configuration (VLCC), which includes homes with underground wiring (UG), ordinary low current configuration (OLCC), ordinary high current configuration (OHCC), and very high current configuration (VHCC). Independent diagramming of selected homes by each of the technicians resulted in excellent reproducibility of wire code assignment.¹¹

In our initial report, cases and controls were matched on age, race, and the first eight digits of the telephone number.^{1,8} We also restricted the original analysis of wire codes to subjects that had lived in one home for 70% of their lifetime (children < age 5) or 70% of the 5 years before the reference date for older children.^{1,8} For the current analysis, we used all 1,159 subjects whose homes were wire coded, regardless of their residential stability, to have the largest number of subjects possible for the analysis. In addition to the 408 residentially stable matched pairs presented in our earlier report,¹ we include 183 subjects under age 3 whose pregnancy homes were wire coded, but who were not eligible for the main wire code analysis because they moved too often. Another 160 subjects had their homes wire coded before we determined the residential stability of both members of the matched pair. All but 28 of these 160 subjects were themselves residentially stable, but were excluded from the original report¹ because the matched subject did not meet eligibility requirements for wire coding. Among the total of 1,159 subjects whose homes were wire coded, there were 107 subjects (26 cases and 81 controls) who declined to participate in the interview phase of the study. Because wire coding did not usually require access to the property and, therefore, subjects'

consent, we were still able to wire code their homes. These subjects had completed two telephone interviews but refused an in-person interview, and were characterized as "partial participants."

MAGNETIC FIELD MEASUREMENTS

For each home, the summary MF measurement consisted of a time-weighted-average (TWA) of magnetic fields based on a 24-hour bedroom measurement and 30-second family room and kitchen measurements, weighted by an estimate of the amount of time spent in each room, according to the child's age.^{8,12} We were less restrictive in terms of residential stability for the measurement, as opposed to the wire coding, component of the study, and measured multiple homes as long as they collectively covered 70% of the reference period. For this analysis, we report data on magnetic fields from the home that was occupied the longest for the 629 cases and 619 controls used in the report by Linet et al.¹ A total of 147 subjects (48 cases and 99 controls) did not allow us to measure magnetic fields inside the home they had lived in the longest, but did allow a measurement within 3 feet of the front door. Front door measurements correlated well with interior measurements ($r = 0.79$), and were substituted for the 24-hour and indoor spot measurements when we computed TWA for each home.⁸ The 147 subjects with no interior measurement were considered "partial participants" in the analyses of potential selection bias.

COLLECTION OF DATA ON RESIDENTIAL, SOCIODEMOGRAPHIC, AND OTHER FACTORS

Information on covariates was collected during three separate interviews.^{1,8,13} The Children's Cancer Group initially identified the cases and controls, and interviewed subjects' parents by telephone to collect data on sociodemographic factors, type of area lived in at diagnosis (urban, suburban, rural, or farm), and numerous potential risk factors for ALL. During the second phase of the study, National Cancer Institute (NCI) interviewers telephoned parents of eligible subjects to obtain a residential history from conception to the date of diagnosis. Interviewers asked many details about current and former residences, including the source of heat, presence of air conditioning, type of building materials and whether the home was a single family or other type of residence. Finally, during the third phase of the study, data collectors visited eligible residences to measure magnetic fields and conduct a personal interview with the subject's mother on appliance use and other factors.¹³

ANALYSIS

We examined two-way frequency tables of the distribution of numerous residential, sociodemographic, and behavioral characteristics within levels of wire code and MFs to determine which variables were strongly related to exposure. We categorized the summary time-weighted-average (TWA) magnetic field measurements

into four levels, $<0.065 \mu\text{T}$, $0.065\text{--}0.099 \mu\text{T}$, $0.100\text{--}0.199 \mu\text{T}$, and $\geq 0.200 \mu\text{T}$, based on the levels chosen a priori for analysis in our earlier report.¹ We also examined the association of covariates with the TWA categorized as $<0.065 \mu\text{T}$, $0.065\text{--}0.099 \mu\text{T}$, $0.100\text{--}0.299 \mu\text{T}$, and $\geq 0.300 \mu\text{T}$. Overall, the correlations were very similar, so we only present the results using $\geq 0.200 \mu\text{T}$ as the highest category in the appendices.

We used logistic regression models for unmatched data to explore the relation between childhood ALL, level of wire code, and potential confounding variables. Potential confounders were chosen based on a priori hypotheses, results reported in our previous analyses,^{1,13} and analyses of tabular data, as described above. We added each variable individually to a model containing subject's age (<5 , $5\text{--}9$, and $10+$) and gender and computed the percent change in the risk of ALL according to wire code levels. We also explored whether simultaneous adjustment for multiple variables changed ALL effect estimates. The same modeling procedures were repeated for the two categorizations of MF measurement data. The models were based on the subset of cases and controls for which complete data on all covariates were available, which included 521 cases and 447 controls for the wire code analysis, and 590 cases and 522 controls for the analyses of measurement data. In both analyses, most subjects who were excluded from the models because of missing covariates had refused to participate in the in-person interview phase of the study.

To evaluate whether there was any evidence of selection bias in our study, we compared odds ratios for the four levels of wire code between two groups of subjects: "complete" participants ($N = 1052$) and the entire group of subjects ($N = 1159$) including the 107 subjects who declined to be interviewed. Likewise, we compared our measurement results (front door and TWA) using the total number of subjects ($N = 1248$, 629 cases and 619 controls reported by Linet *et al.*¹ with those obtained when the 147 subjects who had refused indoor measurements were excluded ($N = 1101$). We also compared the characteristics of "complete" participants and those who refused to participate at a certain point ("partial" participants) to determine whether there were systematic differences between the two groups.

Results

Both wire code level and MF measurements were more strongly related to residential characteristics than to sociodemographic, reproductive, or behavioral variables (see Appendices 1 and 2). The majority of residences in our study were single family homes that tended to have both low wire code categories and low measured fields. Apartments in houses, or duplexes and rowhouses were more likely to have a wire code level of VHCC and have MFs $\geq 0.2 \mu\text{T}$ than other types of homes. Building materials (wood, brick, stone, concrete or cement, or aluminum siding) were not related to either wire codes or measured MFs (data not shown).

Few residences used electric heat as their primary source of heat, but these homes tended to have lower

wire codes than homes with other sources of heat. Homes with central air conditioning had both lower wire code levels and were less likely to be characterized by magnetic field levels of $0.2 \mu\text{T}$ or more than homes with window air conditioners or no air conditioning.

Homes located in urban areas had higher wire code levels and higher measured magnetic fields, whereas homes in rural areas had the lowest wire code and MF levels. The existence of new construction projects (shopping centers, housing developments) within five blocks of the home was unrelated to either wire code or magnetic fields (data not shown).

In general, wire codes and measured MFs were not strongly related to sociodemographic characteristics (see Appendices 1 and 2). There were few differences by level of total family income at the reference date, although homes of subjects in the highest income category were less likely to be in the VHCC category than homes of subjects in other income categories. Residents who reported an income less than \$20,000 per year were somewhat more likely to have a summary TWA field over $0.2 \mu\text{T}$, but the other income categories showed little variation in measurements. There was no important variation in wire code or MF level of residences according to either maternal education or occupation; however, homes of mothers who were unmarried at the reference date had higher wire code and MF levels. Rental homes had both higher wire codes and measured MFs, owing to the tendency for rental units to be located in urban areas. A child's residential mobility was unrelated to wire code level. Subjects who had lived in three or more homes during their lifetime, however, were slightly more likely to have magnetic field levels $>0.2 \mu\text{T}$ in their longest lived in home.

Neither wire code nor MF levels were strongly related to the number of live births that the mother had before the reference date, to maternal or paternal age at the birth of the index subject, or to the mother's age at first birth. Breast feeding the index child tended to be associated with lower wire code levels, but was unrelated to directly measured fields. In contrast, current smoking habits (at the time of the first telephone interview) of either the mother or father were unrelated to wire code, but the father's current smoking habits were associated with higher measured magnetic fields in the longest lived in home.

Maternal use during pregnancy of selected appliances (sewing machines, electric blankets, and television) was unrelated to either wire codes or measured fields (data not shown). Except for television and electric blanket use, children's use of appliances was not correlated with either wire codes or direct measurements. The amount of time spent watching TV was inversely related to level of wire code, but positively associated with measured fields. Children who used electric blankets were slightly less likely to have high magnetic fields in their homes, but there was no major difference according to wire code level.

TABLE 1. Percent Change in Odds Ratios (OR)* for Very High Current Configuration (VHCC) Category, Compared to Underground (UG)/Very Low Current Configuration (VLCC) Category, and for Magnetic Field Level $\geq 0.2 \mu\text{T}$ and $\geq 0.3 \mu\text{T}$, Compared to $< 0.065 \mu\text{T}$, When Indicated Covariates Added to Model Containing Age and Sex Only

Covariate	% Change to OR for VHCC Category	% Change to OR for $\geq 0.2 \mu\text{T}$ Category	% Change to OR for $\geq 0.3 \mu\text{T}$ Category
Type of residence	-5.7	-6.8	-7.5
Home ownership	-0.8	-5.1	-4.4
Primary source of heat	-4.1	-1.7	-1.9
Type of air conditioning	-4.1	-1.7	-3.1
Type of area	-4.1	-4.2	-5.6
Family income at reference date	-4.1	0.8	0.0
Maternal education	0.0	0.0	-0.6
Maternal marital status	0.8	-0.8	-0.6
Total number of homes lived in by child from conception to reference date	-1.6	-0.8	-0.6
Breast feeding of index child	-2.4	-0.8	-1.9
Current smoking by mother or father	-0.8	-1.7	-1.3
Mother used electric blanket in pregnancy	-0.8	0.0	0.6
Mother used sewing machine during pregnancy	0.0	0.0	1.3
Child used electric blanket	1.6	0.8	1.3
Time spent watching TV (child)	1.6	-5.1	0.0
Multivariate model	-15.0	-15.0	-11.9

* Percent change in OR is equivalent to the confounding risk ratio plus one.

RESULTS OF MODELS TO EVALUATE CONFOUNDING

No variable individually changed the estimate of the effect of living in a VHCC home in relation to leukemia by more than 6% (Table 1) when added to a model containing age and sex alone. Similar results were found for the OLCC and OHCC wire code levels (data not shown). Although no individual variable was a strong confounder of the wire code/ALL relation, the majority of potential confounders reduced the estimate for VHCC (Table 1). When we controlled simultaneously for variables that reduced the estimate by at least 4% (type of residence, type of area, primary source of heat, type of air conditioning, and family income), the effect estimate for ALL among those in VHCC homes was reduced by 15%.

As in the results for wire coding, we found little change in the effect estimates for the highest categories of magnetic fields with the addition of potential confounding variables one at a time (Table 1). Type of residence, the strongest confounder, changed the estimate by only 8%. Controlling simultaneously for type of residence, type of area, home ownership, and the time that the child spent watching TV, we found that the estimate for the $\geq 0.2 \mu\text{T}$

category was reduced by 15%. For the model examining the effect of magnetic fields $\geq 0.3 \mu\text{T}$, we controlled simultaneously for type of residence and type of area and found that the estimate was reduced by 12%.

EVALUATION OF SELECTION BIAS

Subjects who did not allow indoor measurements and/or were not interviewed appeared to differ systematically from subjects who willingly participated in all phases of the study (Table 2). For example, "partial" participants were less likely to live in single family homes, more likely to rent their homes, and nearly twice as likely to have low incomes as "complete" participants were. Mothers of subjects who did not fully participate had lower levels of education and were more likely to be unmarried. Complete and partial participants were similar in terms of urbanicity, but partial participants had slightly higher magnetic field and wire code levels. These systematic differences were evident among both case and control partial participants, but tended to be stronger among controls. For example, 24% of control partial participants had incomes $< \$20,000$, compared with 9% of control complete participants. Among cases, 18% of case partial participants had incomes

TABLE 2. Selected Characteristics of Subjects with Indoor Magnetic Field Measurements vs Subjects with Front Door Magnetic Field Measurements Only and of Wire Coded Subjects with and without In-Person Interview

Characteristic	Subjects with Indoor Measurements (N = 1101)	Subjects with Front Door Measurements Only (N = 147)	Wire Coded Subjects with Interview (N = 1052)	Wire Coded Subjects without Interview (N = 107)
% Living in single family home	83%	58%	78%	70%
% With income $< \$20,000$	12%	23%	14%	29%
% Mothers with \leq high school education	38%	46%	40%	55%
% Rented residence	18%	40%	22%	35%
% Unmarried mothers	10%	25%	13%	22%
% Urban	22%	23%	25%	30%
% $> 0.2 \mu\text{T}$	12.7%	15.6%		
% VHCC	6.3%	8.8%	6.7%	8.4%
% Controls	47%	67%	48%	76%

Compared to
μT and ≥0.3

% Change
to OR for
μT Category

-7.5
-4.4
-1.9
-3.1
-5.6
0.0
-0.6
-0.6
-0.6
-1.9
-1.3
0.6
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TABLE 3. Effect of Selection Bias from Exclusion of Partial Respondents from Logistic Regression Models, and Joint Effect of Selection Bias and Confounding

	OR (95% CI)* for Living in VHCC† vs UG/VLCC‡ Home		OR (95% CI)* for Living in Home With TWA MF ≥ 0.2 μT vs <0.065 μT		OR (95% CI)* for Living in Home With TWA MF§ ≥ 0.3 μT vs <0.065 μT	
	OR	95% CI	OR	95% CI	OR	95% CI
Model using complete participants only , controlling for age and sex	1.23	0.74-2.04	1.35	0.92-1.96	1.90	1.10-3.27
Model using all participants§, controlling for age and sex	1.00	0.62-1.61	1.20	0.84-1.69	1.60	0.98-2.61
Model using all participants, controlling for additional confounding variables**	0.82	0.50-1.36	1.07	0.74-1.55	1.45	0.87-2.40

* Odds ratio (95% confidence interval).

† Very high current configuration.

‡ Underground/very low current configuration.

§ Time-weighted-average magnetic field.

|| Wire code model based on 549 cases and 503 controls; MF models contain 581 cases and 520 controls.

¶ Wire code model based on 575 cases and 583 controls; MF models based on 629 cases and 619 controls.

** For wire code model, additional confounding variables were type of residence, type of heating, air conditioning, type of area lived in, and total annual family income. For MF models, additional confounding variables were type of residence, type of area, and home ownership.

<\$20,000 vs 15% of case complete participants. As expected, control subjects were more likely than cases to refuse to participate in one or more phases of the study. The exposure distributions were quite different among case and control partial participants. For example, none of the 26 cases vs 11% of the 81 controls that declined to be interviewed lived in a VHCC home. Similarly, 10% of the 48 cases vs 18% of the 99 controls that did not provide interior measurements had front door measurements over 0.2 μT.

When we compared the actual effect estimates that were obtained using all of the subjects vs including complete participants only, there was some evidence for selection bias (Table 3). For example, when all subjects with wire coded homes were included in a model adjusted for age and sex, the odds ratios for leukemia risk were 1.09 for OLCC, 1.05 for OHCC, 1.00 for VHCC, compared with subjects living in VLCC/UG homes. These results are similar to those reported by Linet *et al.*,¹ although here we report unmatched results, and include 343 additional wire coded homes. When we excluded the 107 subjects who declined to be interviewed, the odds ratios increased slightly in all three wire code categories (OR for OLCC = 1.14; 95% CI = 0.86, 1.53; OR for OHCC = 1.18; 95% CI = 0.85, 1.64; OR for VHCC = 1.23; 95% CI = 0.74, 2.04) (Table 3).

We found similar results when we excluded the 147 subjects who did not allow indoor MF measurements from the models that examined ALL risk according to levels of MF exposure (Table 3). The odds ratio for having a front door measurement over 0.2 μT increased from 1.16 (95% CI = 0.83-1.62) among the whole group of 1,248 subjects to 1.29 (95% CI = 0.90-1.84) when the 147 partial participants were excluded. For front door measurements above 0.3 μT, the odds ratio increased from 1.52 (95% CI = 0.97-2.40) to 1.72 (95% CI = 1.05-2.81) in the smaller subset of subjects. Likewise, the OR for TWA >0.2 μT increased from 1.20 to 1.35 and for ≥0.3 μT, it increased from 1.60 to 1.90.

Because many of the potential confounding variables were collected during the first and second phases of data

collection, we were able to evaluate the effect of selection bias and confounding simultaneously (Table 3). When additional covariates were included in a model based on all participants, the OR for living in a VHCC home was further reduced from 1.00 to 0.82. Similar, slightly smaller reductions in the estimates were found when confounding variables were added to the MF measurement models using all participants.

Discussion

This is the first study to evaluate the relation between a large number of residential, sociodemographic, and behavioral characteristics and both wire codes and magnetic field measurements over a large geographic area. This is also the first analysis to provide effect estimates for childhood ALL with and without partial participants and to demonstrate differences in effects when families not participating in the interview or indoor magnetic field measurements are excluded. Unlike previous studies examining the relation of potential confounding variables and wire code levels,^{6,9,10} our study was conducted in a spectrum of urban, suburban, and rural settings, and the data were derived directly from a study of childhood ALL. We found strong associations between several residential and subject characteristics and both wire codes and magnetic fields measured in homes. In general, these relations were similar for both wire codes and measured fields, a finding that was not surprising in view of the correlation we observed between wire codes and measurements.¹¹

Similar to the findings from Jones' study of 5,721 homes in Columbus, Ohio,⁶ we found that apartments, rowhouses, and duplexes and homes located in urban areas had higher wire codes and MFs than single family homes or homes located in suburban or rural areas. Unlike our study, Jones found that residential mobility was associated with higher wire code levels. Our study was designed to focus on more residentially stable subjects, which may account for the different findings.

We found little evidence for an association between income and wire codes, in contrast to studies in Seattle⁹ and Columbus, Ohio,⁶ which reported an inverse association between income and wire code levels. Bracken *et al*¹⁰ found that wire codes were inversely related to the size and the assessed value of residences. These divergent findings may be explained by the large geographic area included in our study, in contrast to previous studies that have taken place in a single city. We did find that homes in the lowest income category tended to have slightly higher measured magnetic fields, but there was no evidence of any trend with income. We found little association between maternal educational level or occupation and wire code or measured fields, but similar to Bracken *et al*,¹⁰ we found that unmarried mothers were more likely to live in VHCC homes.

Despite the univariate associations between several variables and wire codes and magnetic field measurements, we found little evidence that any single variable was an important confounder of the relation between wire code or magnetic field level and risk of childhood ALL. No variable changed any of the effect estimates for wire code level or measured fields by more than 8%. When variables were considered simultaneously in models, the estimates changed by a maximum of 15%. If the associations we observed also hold true in other studies, then confounding by itself might be responsible for a small upward bias in the effect estimates, but is not likely to explain completely the reported associations between wire codes and childhood ALL.²⁻⁴ Of course, if there were an important unmeasured confounder, we would not be able to assess its potential effect, but this possibility seems unlikely, given the paucity of known risk factors for childhood leukemia, particularly among correlates of wire codes or magnetic fields. We did not have information on age of the home or traffic density, which has been reported to be associated with wire codes.^{10,14}

A unique feature of our study was the inclusion of information that allowed us to evaluate possible selection bias, albeit on a limited scale. Most case-control studies are unable to evaluate the likelihood of selection bias because of the lack of information on the exposure distribution of non-respondents.^{15,16} Studies that have collected data on non-respondents have shown that they tend to be characterized by lower socioeconomic status, poorer health, and higher levels of smoking than participants.^{17,18}

Except for the wire code distribution of a small proportion of subjects who refused to participate during the initial recruitment phase of the study, we lacked information on non-respondents. As a result we were unable to assess the effect of selection bias from excluding subjects who never participated in any phase of the study (4% of eligible cases and 25% of controls who were found eligible for the study during random digit dialing). Unlike many case-control studies, however, we were able to compare the characteristics of subjects who refused participation at some point in the study with those who fully participated because data were collected in three sequential phases. Several systematic differences were apparent. As expected, controls were more likely to

be partial participants than cases. In general, partial participants were characterized by lower socioeconomic status, according to measures such as income, education, marital status, type of home, and home ownership. These results were evident in both cases and controls, but tended to be stronger among controls. Also, controls who were partial participants were much more likely to live in VHCC homes and somewhat more likely to live in homes with MF levels $>0.2 \mu\text{T}$ than case partial participants.

The systematic differences between complete and partial participants increased the effect estimates that we observed. When partial participants were excluded from the wire code analysis, the estimate for subjects living in a VHCC home increased by 23%. We found similar but slightly smaller increases in the ORs (from 11% to 19%) when partial participants were excluded from the analyses of MF measurements. When confounding and selection biases were considered together, the change in estimates was even larger than when each bias was evaluated separately. The OR for VHCC homes increased by 50%, and the OR for measured fields increased by 31% when models among complete participants without control for confounding were compared with models among all participants controlling for confounding variables.

Considering that partial participants had cooperated in an earlier phase of the study, it seems likely that subjects who refused at the outset of the study may have differed even more strikingly from the "complete participants." This difference may have led to an even greater upward distortion of the results than would have occurred if a higher proportion of controls had participated in the study. A total of 25% of controls refused to participate during the initial phase of data collection. This figure does not include potential controls who did not provide enough information to the telephone interviewer to determine eligibility.

Selection bias due to non-participation or differential restrictions placed upon cases and controls may have affected the results of previous studies.³⁻⁵ In the Denver study, different residential stability requirements were placed upon cases and controls.³ If residentially stable controls were also more likely to reside in neighborhoods with low exposure levels, a spurious relation may have resulted. In the Los Angeles study, cases were more likely than controls to have lived in their home for their whole lives, suggesting that residential stability might have also been a factor in this study.¹⁹ Also, subjects in the Los Angeles study who refused to participate at either the random digit dialing or interview stage did not have their homes wire coded.⁴ In contrast, we were able to assess the wire codes of the homes of subjects who refused to participate in the second, detailed interview or allow access inside their home, as long as we had information on their residential history. Therefore, selection bias may have been reduced in the NCI/CCG study compared with earlier U.S. studies,^{3,4} which might partially explain the differing wire code results among these three studies. We could not measure magnetic fields, even outside the front door, without consent. Therefore, selection bias may have affected our magnetic field

measurement results more than our wire code results. Unless investigators can improve the response rates of controls in future studies,²⁰ obstacles will remain in evaluating the relation between magnetic fields and cancer.

In summary, our analysis found that selection bias and, to a lesser extent, confounding had detectable effects upon the results. Although several variables were strongly related to both wire codes and measurements, it seems unlikely that confounding alone can explain the findings of previous studies. Selection bias, in contrast, led to a slight overestimate of effect in our study,¹ which was magnified when confounding was also considered, and could explain part of the association between wire codes and childhood leukemia reported in past studies.

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Appendices

APPENDIX 1. Percent Distribution of Wire Code* Categories in 1,159 Homes by Selected Residential, Sociodemographic, and Behavioral Characteristics

	Wire Code Category				Total†
	UG/VL† N = 491	OLCC N = 340	OHCC N = 248	VHCC N = 80	
Type of residence					
Single family home	40.9	32.6	20.6	5.9	895
Apartment in building	61.8	7.9	22.4	7.9	76
Apartment in house, duplex, rowhouse	25.2	28.5	30.1	16.3	123
Trailer	72.3	10.8	15.4	1.5	65
Primary source of heat					
Electric	65.5	15.1	16.6	2.9	139
All other	39.3	31.2	22.1	7.4	1016
Type of air conditioning					
Central	54.4	25.4	16.3	3.8	417
Window	31.6	31.8	26.7	9.9	393
None	39.9	31.3	21.6	7.2	348
Type of area					
Urban	25.4	37.0	27.1	10.5	295
Suburban	40.3	29.8	23.8	6.2	504
Rural	58.9	23.6	12.0	5.4	258P
Farm	59.0	20.0	17.0	4.0	100
Total family income					
<20,000	39.4	30.0	22.2	8.3	180
20-29,000	40.8	28.8	20.7	9.8	184
30-39,000	40.6	30.1	22.4	6.9	219
40-49,000	41.5	27.9	25.7	4.9	183
≥50,000	45.8	29.4	18.8	6.0	384

APPENDIX 1. Continues

	Wire Code Category				Total‡
	UG/VL† N = 491	OLCC N = 340	OHCC N = 248	VHCC N = 80	
Mother's level of education					
High school or less	40.1	31.1	22.5	6.3	479
Post HS training/some college	43.3	26.7	22.6	7.4	367
College graduate	44.7	29.6	18.3	7.4	311
Father's level of education					
High school or less	42.2	29.7	21.5	6.6	455
Post HS training/some college	42.2	27.0	23.6	7.4	326
College graduate	45.7	29.8	18.4	6.1	326
Mother's occupation					
Professional	42.0	33.2	19.2	5.6	250
White collar	42.6	30.5	19.5	7.4	298
Blue collar	40.3	27.4	24.2	8.1	62
Homemaker	42.6	27.1	23.1	7.1	549
Father's occupation					
Professional	48.1	27.4	18.7	5.8	347
White collar	37.1	35.6	20.5	6.8	205
Blue collar	43.5	26.8	22.0	7.7	478
Marital status					
Currently married	43.6	29.6	20.4	6.4	996
Single, divorced, separated, widowed	34.4	28.0	27.4	10.2	157
Own/rent home					
Own	43.4	30.2	20.6	5.8	884
Rent	38.5	26.3	24.4	10.7	270
Total number of homes lived in from conception to diagnosis/reference date					
One	39.9	31.9	20.4	7.8	486
Two	44.3	26.5	22.8	6.4	359
Three or more	44.0	28.7	21.3	6.1	314
Total number of live births prior to diagnosis/reference date					
One	41.5	31.1	17.7	9.8	164
Two	45.3	26.0	21.8	6.9	523
Three	40.6	34.7	18.9	5.8	291
Four or more	37.2	28.9	27.8	6.1	180
Mother's age at 1st live birth					
<20	36.4	30.3	28.8	4.6	187
20-24	42.1	30.2	21.8	6.0	454
25-29	44.8	26.8	20.5	7.9	366
30+	45.0	29.1	20.5	5.3	151
Mother's age at index birth					
<20	36.4	30.3	28.8	4.6	66
20-24	44.6	30.3	19.1	6.0	267
25-29	38.3	30.1	24.2	7.5	439
30+	46.4	27.7	18.7	7.3	386
Ever breast fed					
No	37.7	31.4	23.8	7.1	379
Yes	46.9	29.0	17.6	6.5	644
Father's age at index birth					
<20	34.8	47.8	13.0	4.4	23
20-24	46.4	26.2	22.0	5.4	168
25-29	39.2	30.8	22.1	7.9	380
30+	45.5	27.4	20.7	6.4	532
Mother current smoker					
No	42.4	30.2	20.7	6.7	879
Yes	41.9	27.1	23.8	7.2	277
Father current smoker					
No	44.2	29.5	20.1	6.1	765
Yes	41.1	28.1	22.6	8.2	331
Use of selected appliances by child					
Electric blanket					
No	43.5	30.0	19.7	6.8	981
Yes	43.2	31.8	20.5	4.6	44
TV					
<2 hrs/day	51.7	20.1	17.2	10.9	174
2-4 hrs/day	43.7	30.9	20.0	5.3	375
4-6 hrs/day	39.6	33.3	20.4	6.7	255
>6 hrs/day	40.7	31.9	21.3	6.0	216

* Electrical wiring configurations classified by the Wertheimer-Leeper² method of wire coding.† UG and VLCC categories combined to correspond to Linet *et al.*¹

‡ Individual variable totals may not equal the total number of wire-coded homes due to missing values.

APPENDIX 2. Percent Distribution of Magnetic Field Levels in 1,248 Homes by Selected Residential, Sociodemographic, and Behavioral Characteristics

		Summary Time Weighted Average Magnetic Field Levels*					
		<.065 μ T N = 590	.065-.099 μ T N = 217	.100-.199 μ T N = 278	.200+ μ T N = 163	Total† 1,248	
479		Type of residence					
367		Single family home					1000
311		Apartment in building					61
455		Apartment in house, duplex, rowhouse					115
326		Trailer					72
326		Primary source of heat					
		Electric					141
250		All other					1103
298		Type of air conditioning					
62		Central					487
549		Window					401
		None					357
347		Type of area					
205		Urban					278
478		Suburban					567
		Rural					293
996		Farm					109
157		Total family income					
		<20,000					167
884		20-29,000					200
270		30-39,000					246
		40-49,000					213
486		\geq 50,000					413
359		Mother's level of education					
314		High school or less					487
		Post HS training/some college					412
164		College graduate					348
523		Father's level of education					
291		HS or less					465
180		Post HS training/some college					359
		College graduate					375
187		Mother's occupation					
454		Professional					275
366		White collar					331
151		Blue collar					58
		Homemaker					584
66		Father's occupation					
267		Professional					396
439		White collar					212
386		Blue collar					513
		Marital status					
379		Currently married					1098
644		Single, divorced, separated, widowed					133
		Own/rent home					
23		Own					996
168		Rent/other					245
380		Total number of homes lived in from conception to diagnosis/reference date					
532		One					510
		Two					366
879		Three or more					372
277		Total number of live births prior to diagnosis/reference date					
		One					157
765		Two					545
331		Three					351
		Four or more					195
		Mother's age at 1st live birth					
981		<20					172
44		20-24					499
		25-29					425
174		30+					152
375		Mother's age at index birth					
255		<20					51
7		20-24					282
0		25-29					507
		30+					408
		Ever breast fed					
		No					400
		Yes					773
		Father's age at index birth					
		<20					18
		20-24					179
		25-29					422
		30+					576

APPENDIX 2. Continues

	Summary Time Weighted Average Magnetic Field Levels*				Total†
	<.065 μ T N = 590	.065-.099 μ T N = 217	.100-.199 μ T N = 278	.200+ μ T N = 163	
Mother current smoker					
No	48.3	18.0	21.6	12.1	954
Yes	44.0	14.7	25.3	16.0	293
Father current smoker					
No	49.0	18.4	21.9	10.7	836
Yes	45.1	14.4	23.0	17.5	348
Use of selected appliances by child					
Electric blanket					
No	47.4	16.9	22.4	13.3	1115
Yes	43.3	28.3	20.0	8.3	60
TV					
<2 hrs/day	49.4	18.8	20.0	11.9	160
2-4 hrs/day	51.9	16.3	20.2	11.7	455
4-6 hrs/day	46.8	16.7	21.7	14.7	299
>6 hrs/day	39.1	18.7	27.3	14.8	256

* TWA based on weighted average of 24-hour measurement in child's bedroom, plus 30-second spot measurements in 3 other rooms.

† Individual variable totals may not equal the total number of homes with MF measurements due to missing values.